RESEARCH TRIANGLE INSTITUTE

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CANDIDATE CONCEPT DESCRIPTION FOR SVS/EVS RETROFIT IN AIRPLANES WITH CRT TYPE PRIMARY FLIGHT INSTRUMENTATION

TECHNICAL REPORT

NASA Contract NAS1-99074

Task Assignment 1034

Prepared for

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By

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1.0 Introduction

This document describes work done under NASA Contract NAS1-99074 Task 34, titled "Planning, Requirements Definition, Research and Technical Development of the Tactical Air Operations Component of the Synthetic/Enhanced Vision System". Specifically, this document is intended to satisfy the Deliverable 1 of the Statement of Work entitled "Candidate Concept Description". This document describes the functional requirements for the Synthetic/Enhanced Vision System across all phases of flight. It relates the functional requirements to a set of system capabilities that have been identified from inputs by representatives of the airplane manufacturing, avionics manufacturing, airline, pilot, controller, airport, regulatory, research/development and academic communities. It then described a phased approach to achieving the desired system capabilities that uses a building block approach to retrofit implementation of the candidate concepts into airplanes that have CRT type of primary flight instrumentation.

1.1 Background

In response to the report from the White House Commission on Aviation Safety and Security, President Clinton in 1997 set a goal to reduce the fatal aviation accident rate by 80% within ten years. NASA through the Aviation Safety Program took up the challenge to conduct research that will address the President's goal and result in airspace/airplane system improvements that will contribute to a five-fold reduction in aviation accidents by the year 2007, and a ten-fold reduction in aviation accidents by 2017. The Crew Systems Branches (CVIB and CSOB) at NASA Langley Research Center are leading and performing research efforts to increase aviation safety by focusing on the pilot/vehicle components of the airspace system. Target research areas of this effort include: Synthetic Vision Systems (SVS), enhancing the flight crew's awareness of not only the position of their aircraft in the airspace but also the position of potential obstacles/hazards relative to their aircraft; crew/vehicle interfaces; flight deck design; human performance assessment; and the application and certification of advanced technology.

For air operations, Approach and Landing accidents and CFIT remain top priorities for improved safety. Data from many safety studies indicate that approximately 56 percent of the jet-fleet accidents happen during the approach and landing phases of flight while these phases comprise only 16 percent of the flight duration[1]. The Flight Safety Foundation studied 287 fatal approach and landing accidents occurring between 1980 and 1996[2]. This study listed as the five (out of a possible 64) most frequently identified primary cause of the accidents as: 1) omission of action/inappropriate action (24.7%); 2) lack of positional awareness in the air (18.6%); 3) Flight handling (12.2%); 4) “Press-on-ites” (11.1%); and 5) poor professional judgement/airmanship (4.3%). As can be seen, these five causes account for 71% of the accidents investigated. In defining the first two causes, the study said, ”the most common primary causal factor, ‘omission of action/inappropriate action,’ generally referred to the crew’s continuing their descent below the decision height (DH) or minimum descent altitude (MDA) without visual reference, or when visual cues were lost. The second most frequent factor, ‘lack of positional awareness in the air,’ generally involved a lack of awareness of proximity to high ground….”.

January 22, 2001, two airplanes loaded with passengers came within “yards” of each other on the active runway at Seattle Tacoma International Airport. An American Airlines passenger aircraft (63 passengers) which had landed on runway 16 Right turned onto a taxiway and crossed runway 16 Left as a TWA passenger aircraft (103 passengers) took off from that runway. The TWA jet passed directly over the American Airlines aircraft. It was dark, and visibility was officially about 1300 feet with patchy fog. This incident happened even though Seattle Tacoma International Airport has the most advanced marking, lighting and signage system available and is one of the few airports in the world that is certified for Category IIIb operation. Runway incursions and surface operations incidents/accidents are a serious problem according to the FAA. Incursions are up dramatically doubling since 1994 to an all time high of over 400 last year.

The mission of the Synthetic/Enhanced Vision System (SVS/EVS) is to enhance safety and enable consistent gate-to-gate aircraft operations in normal and low visibility. In order to accomplish this mission, the objective is to increase the situation awareness of flight crews by presenting information about their surroundings that may be denied them by adverse visibility conditions. It is conceived to be a system of sensors, databases, computers, displays, and controls that will present visual representations of the environment. Figure 1-1 provides a graphical representation of some of the conditions that could be addressed by the Synthetic/Enhanced Vision System.

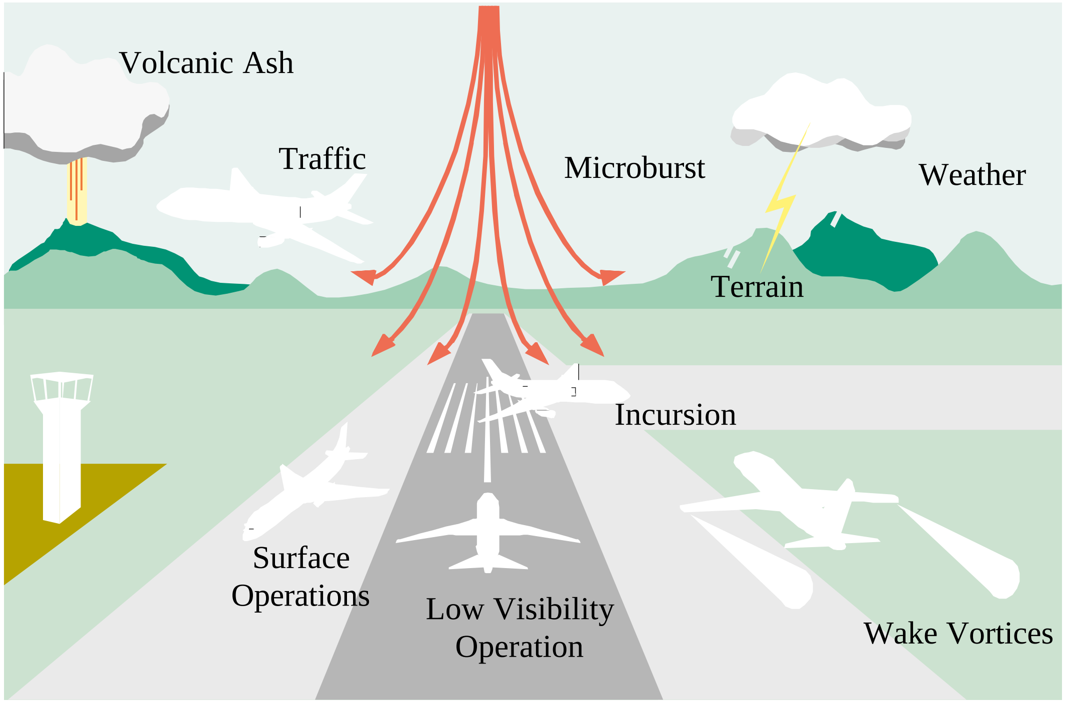

Figure 1-1. SVS/EVS Potential Capabilities for Situation Awareness

1.2 Goal

The purpose of this document is to relate requirements to capabilities to system concepts in such a way as to provide rationale for system element downselect choices. In accomplishing this goal it should be possible to represent the candidate concepts for retrofit into CRT flight decks in terms of components and benefits, as well as describe some of the issues related to selection of technology and components.

This document is intended to be an upper level description of the candidate concepts for retrofit into airplanes with CRT type primary flight instrumentation. Definition and specification of the actual hardware technology and architecture for the concepts can be found in the documents for the system experimentation.

1.3 System Components

In December 2000 Norman[3] stated that, the SVS Concept is assumed to consist of the following elements:

1.3.1 SVS Sensors (or sensor equivalents)
- Forward Looking Infrared (FLIR) (potential)
- Weather Radar (Potential SVS Modes)
- Millimeter Wave Radar (potential)
- Onboard SVS Data Base

1.3.2 Displays
- Primary Flight Display, or imbedded display features
- Navigation Display, or display features/pages
- Head Up Display (option) with dedicated display features
- Interface with Other Cockpit Displays, i.e., TAWS

1.3.3 Computers/Imbedded Computational Functions
- Image Object Detection and Fusion
- System Integrity, Verification and Validation
- SVS Computations and Symbol Generation

1.3.4 Equipment
- Dedicated SVS Support Equipment and Crew Interface
- Interface with Other Aircraft Systems

1.3.5 Associated Aircraft Systems
- Differential Global Positioning System (DGPS)
- Inertial Reference Unit/Attitude Heading Reference Set (IRU/AHRS)
- Air Data Computer
- Radio/RADAR/Laser Altimeter (R/A)
- Traffic Collision Avoidance System (TCAS)
- Data Link (aggregate of IFF Mode S, ADS/B, etc.)

These potential system elements were evaluated with respect to the system functional requirements for all flight phases and the desired capabilities of the system. They are viewed as the available building blocks of the candidate retrofit concepts. In addition to those listed above, Global Positioning System (not dependent on differential signals), Cockpit Display of Traffic Information displays and Vertical Situation Displays were included in the set of potential building block.

2.0 FUNCTIONAL REQUIREMENTS

One of the key elements in the successful transitioning of technology from research and development to a product application is the use of a top-down, requirements-driven, systems-oriented approach to the concept development. The systems orientation promotes the identification and evaluation of all the components that contribute to the end-to-end system operation. This approach can lead to near service ready technologies that are developed to meet defined airplane requirements and will integrate not only into the airplane system but also into the overall airspace system. An orderly process employing validated requirements as the success criteria and used in the concept formulation, development evaluation, and flight validation, as well as in the development of a certification basis, reduces the risk and flow time for the technology. Therefore to achieve the goal of a cost effective Synthetic/Enhanced Vision System that provides gate-to-gate functionality in normal and low visibility conditions, the first step is to define the operational and functional requirements imposed on the system by each phase of flight. The following sections provide a high level description of these requirements and some candidate building block technologies that could be used to achieve the success criteria provided by the requirements.

2.1 Taxi

The operational requirement for the Taxi phase of flight is to move (under visibility conditions down to CAT IIIb and any taxiway surface conditions) from the gate to the take-off point (and return after landing rollout) without contacting obstructions (either static or dynamic), departing the taxiway or causing a safety hazard.

Top-level functional requirements for taxi (both on taxiways and on the runway) include:

<u>Taxi on Taxiways</u>

- Identify and maintain safe distance from taxiway boundaries
- Detect and avoid moving and fixed ground objects around ownship's path
- Track and maintain taxi lines
- Determine position and direction of movement with respect to airport layout
- Determine and comply with information currently provided by taxiway markings and facilities
- Determine the information provided by taxiway lighting
- Detect and avoid airborne hazards to ownship
- Maintain adequate separation following other traffic

- Determine and maintain safe taxi speed for all surface conditions

Taxi on Runway

- Taxi (including U-turn) within the runway boundaries
- Determine and comply with information currently provided by taxiway markings and facilities
- Detect and avoid moving And fixed ground objects around ownship's path on the runway
- Track and maintain runway center line
- Determine position and direction of movement with respect to runway layout
- Determine and comply with information currently provided by runway markings and facilities
- Determine the information provided by runway lighting
- Detect and avoid airborne hazards to ownship
- Maintain adequate separation following other traffic
- Determine safe runway speed for all surface conditions
- Maintain airplane control during high speed taxi
- Distinguish between runway, and overrun, displaced threshold

These requirements focus on four major areas of information that the flight crew needs: the airport information; the cleared taxi route; the position of the ownship; and the position of obstacles/hazards. The flight crew needs to know the layout of the airport, runway/taxiway markings (e.g., lighting, signage, paint marking, etc.) and any unique airport operational limitations (e.g., taxi speeds, gross weight limits). They also need to have precise knowledge of the ATC instructed route to movement and non-movement areas in order to reach takeoff or gate position. These requirements can be met by providing up-to-date airport charts on an active display augmented by data linked taxi routing for the individual airplane. The taxi routing data link message would also provide specific information regarding non-movement areas, gate position and any other information required to perform the taxi flight segment. This will impose additional requirements on the supporting ATC equipment to provide the required information real time and within acceptable controller workloads. The required data for airport layouts impose the need for a data base type source for the information. The changes to this data at all airports within a route structure of a given airline suggest a data base with some form of scheduled update to preclude the accumulation of supplementary modification information to the basic data.

There is also a need for the flight crew to be able to validate these route instructions (e.g., closed taxiways, active runways, holding aircraft, hold lines). Responsibility for validating route instructions always lies with the flight crew. This requirement can be supported by a combination of real time data link data, mass stored data on the airplane and the display of this information in a manner that will complement as appropriate other information provided the flight crew. There is a need to correlate the taxi instructions with the stored flight plan to assure that they both reflect the same active runway. Therefore, the feasibility of a "handshake" between the taxi runway and the stored flight plan takeoff runway (FMC) should be studied.

In order to move along the cleared route, the flight crew needs to know the accurate position of the ownship relative to the airport layout. This requirement can be met by providing Differential GPS plus airport charts/layout on an active display. Without the airport charts, the absolute position of the airplane could be known within 1-3 meters (or less), however, for correlation to the airport layout an airport chart with airplane present position indicated needs to be provided. The flight crew also has to know the position of the ownship relative to the taxiway/runway edges even in conditions which obscure them (e.g., snow, ice, fog, etc.).

During taxi the flight crew needs to be aware of the precise location of fixed and dynamic obstacles or potential hazards relative to the ownship's path in order to safely stop (to clear wings by 20 feet horizontally) at 25 knots taxi speed (worst case). Location of fixed obstacles can be provided by charts on an active display where the airplane position on the airport surface is accurately shown. There are some hazards that are static but are not "fixed" elements of the airport (e.g. closed taxiway). A possible solution to presenting this information could be to provide "data link bulletin" information as a service to all airplanes using the airport. This information could be displayed with the charts when requested, but would be cleared from the system either at the gate on shutdown or on liftoff from the airport.

The requirement to detect and display dynamic obstacles/hazards (e.g., aircraft, service vehicles, baggage carts, cars, snow plows, animals, etc.) may establish a heavy infrastructure burden on system implementation without an active sensor on the ownship. One solution to this requirement may be an active sensor of to provide real time situation information. The sensor data can be overlaid on the airport chart data, which imposes the need for chart scale and sensor range scale compatibility.

From the above, the following building block system elements are viable candidates for the CRT based system concept:

- Differential GPS
- Display (HUD and/or HDD)
- Electronic airport layout/surface charts
- Active Sensor
  - Range to obstacle from own aircraft and closure rate
  - Angular location of obstacles with reference the own path
  - Distance to edge of taxiways/runways
- Data link display(s)
- Mass data storage
- Data link/voice communications for real time airport surface information
  - Taxi route for own aircraft (including changes to published information)
  - Validation of taxi route by flight crew
  - Transient traffic movement

Note: Overlay of charts and sensor information requires scale correlation

There are several issues that need further consideration in developing the candidate concepts. First is a definition of the airport chart formats, accuracy, and update process. Where do you store the airport chart data? If the data is stored in an electronic library then the ELS becomes flight essential and you have to have one on every airplane. If the data is tied to the FMC Database, then the whole thing can be updated at the same time, using the same resources. Most EFIS airplanes have an FMC and an update of these computers will be required to incorporate surface operation information which could also include expanded data storage. There is a need to do trade study on where/how to store this data.

There is a need to have a dialog with controllers to determine the content of the data link messages, the procedures for validation, airplane and controller equipment complement.

The field-of-view and accuracy of any sensors is a very fundamental question that should be given priority attention (particularly the X-band radar with beam sharpening). What can be displayed at what range with what accuracy/reliability? Range and range rate are basic requirements.

2.2 On Runway and Takeoff Roll

The operational requirement for the takeoff flight phase is to conduct departure or RTO within confines of runway under visibility conditions down to CAT IIIb on any runway surface conditions including the avoidance of hazardous weather conditions and obstacles (e.g.: aircraft, vehicles.).

The top-level functional requirements for the takeoff flight phase include:

- Determine location and severity of atmospheric conditions (i.e. windshear, wake vortices)
- Determine and comply with information currently provided by taxiway markings and facilities
- Detect and avoid moving and fixed ground objects around ownship's path on the runway
- Identify and maintain safe distance from runway boundaries
- Determine position and direction of movement with respect to runway layout
- Determine and comply with information currently provided by *runway markings* and facilities
- Determine the information provided by runway lighting
- Detect and avoid airborne hazards to ownship
- Maintain *adequate* separation following other traffic
- Identify and avoid foreign objects *on* the runway
- Determine that runway is clear of conflict before *and* during T/O roll
- Determine whether a safe RTO can be accomplished for any runway surface at any time during the T/O roll
- Track and maintain runway centerline
- Distinguish between runway, and overrun, displaced threshold
- Determine lift off
- Maintain and control desired flight path and energy state
- Compensate for crosswind and engine out conditions

These requirements again focus on four major areas of information that the flight crew needs: the takeoff clearance; ownship performance capabilities; the position of the ownship; and the position of obstacles/hazards. Of primary importance is that the flight crew be able to confirm their takeoff clearance and that they are on the assigned runway. They need to be able to validate the ownship position relative to the active runways. The airport chart with differential GPS airplane position will provide this information to the flight crew. Questions to be addressed include: "How to display this information" and perhaps more important -"How do you correlate this data from the airport chart with data presented by the FMC CDU and map display?" As stated earlier, the feasibility of a "handshake" between the taxi and flight plan data and techniques for displaying runway validation to the flight crew should be investigated. The flight crew then needs to confirm the compatibility of assigned runway with the ownship performance. Airport charts will provide basic runway data. Temporary changes to established charts would have to be handled via data link. Permanent changes will also be handled via data link pending update of the airport information database as discussed in the Taxi section above. The act of confirming airplane performance relative to the runway will be performed by the FMC since it has all of the airplane performance information. The display components will have to provide the flight crew with the confirmation information.

During the time on the runway, the flight crew needs sufficient information to track the runway centerline. This requirement may be met by processed data from an active sensor or derived from precise position information (e.g. differential GPS or ILS/MLS. A review of current FAA airport surface control improvement planning would indicate the use of existing or the addition of edge marking devices would also be a viable consideration. The visual tracking of the centerline-will be deficient anytime there is snow or standing water on the runway. To mitigate this issue, tracking of the edge lights could be more reliable since they would not be obscured as much of the time. The implementation of this option must be able to apprise the flight crew they are within some accuracy of the centerline (this may impose field-of-view design requirements on the involved sensor). In any case, the objective is to provide this information on a display format that will permit visual-out-the-window type operations.

In order for the system to meet the functional requirements for takeoff, the flight crew must be able to recognize (and preferably determine size of) moving obstacles encroaching on aircraft's path. Real time sensor derived situation information could meet this requirement. This functional requirement is comparable to that for the Taxi flight segment to be able to detect movable objects. Data link is another alternative however, it does not see the world from the same perspective that the flight crew has in the ownship. The issues for this requirement remain size/range/etc. so again; it is necessary to work the resolution problem. Angular coverage will be important here since the targets could be other aircraft at close range. The relative azimuth rate for such targets would be very high. The objective is to detect obstacles between the size of a deer and another airplane.

Finally the crew needs to know the location, dynamics and severity of impending hazardous meteorological conditions (e.g., windshear, wake vortices), so that a delay or timely avoidance action can be taken. Weather phenomenon such as thunderstorms and windshear are detected by the improved weather radar and/or improved weather reporting via data link. However, it is important that the available data provide the flight crew with a real-time definition of weather hazards as they relate to the individual airplane path and performance characteristics. Wake vortex detection is another potential system element. A number of major airlines believe that they can achieve substantial increase in traffic throughput if wake vortex detection can be provided with high confidence and low false alarm rates. They are also acutely aware that this is a prime candidate for decreasing safety if it is not done right.

From the above, the following building block system elements are viable candidates for the CRT based system concept:

- Differential GPS
- Display (HUD and/or HDD)
  - Airport surface charts
  - Departure charts
  - Sensor imager
  - Data link readout
- Data link/voice for real-time communications
  - Takeoff ATC instructions /validation
  - Weather services
- Sensor
  - Windshear detection
  - Vortex detection
  - Centerline tracking during takeoff
  - Detection of targets with movement in conflict with own airplane's planned takeoff profile

2.3 Departure

The operational requirement for the departure flight phase is to depart terminal airspace safely according to ATC instructions while avoiding hazardous meteorological conditions and unsafe proximity to other aircraft, terrain and obstacles.

The top-level functional requirements for the departure flight phase include:

- Maintain and control desired flight path and energy state
- Detect and avoid airborne hazards to ownship
- Maintain safe separation from all types of airborne traffic
- Maintain safe separation from ground obstacles (man made & natural)
- Determine location and severity of atmospheric conditions (i.e. windshear, wake vortices)
- Compensate for crosswind and engine out conditions

The primary focus in this flight phase is maintaining the desired flight path and avoiding obstructions/traffic/hazards. The SVS/EVS should provide the flight crew with information that enables them to independently verify the safety of ATC instructions in a timely fashion. The requirement includes the need for the availability of stored data against which the approved flight path can be checked. Sensor information may also be used to clarify overall real time situation for traffic /weather/ etc.

Of major concern in this flight phase is the flight crew's awareness of the position of the ownship relative to obstacles (terrain, manmade) and other aircraft during initial climbout. A candidate concept may require multiple elements for a common solution to providing this information. This requirement is considered to be the real time/continuous check of the airplane position relative to the surrounding space. Awareness of the airplane's proximity to terrain and/or manmade obstacles could be provided by stored data (i.e., contours/ obstacles/ etc) and real time position data. A real time situation assessment may also be provided by a sensor solution with adequate range and resolution to provide flight path surveillance. Again, there may be a need for a multiple element solution; i.e., sensor and data. The question of sensor range, resolution, field-of-view, power output, etc. is again of prime interest.

For awareness of other aircraft during initial climbout, TCAS currently provides one solution to the spherical surveillance problem. Cockpit Display of Traffic Information (CDTI) that uses a number of information sources (e.g., Mode-S, ADS-B, TIS-B etc.) is another potential system candidate for traffic awareness. If it can be assumed that other aircraft within the operating environment are also equipped with appropriate sensor equipment, then there is a cooperative traffic detection capability provided by any forward looking sensors that may be installed with performance levels capable of detecting airborne targets -- this infers range and range rate data will be required.

The crew should be presented information about location of special use airspace boundaries in relation to own aircraft (i.e., military, fuel dumping, noise). This data is normally provided by the "data base for terminal operations and navigation (current FMC database)." These boundaries are not dynamic and the FAA or the airlines using special notices as appropriate could handle changes.

Finally, the flight crew needs information on the location dynamics and severity of impending hazardous meteorological conditions, (e.g., windshear, thunderstorms), so that timely avoidance action can be taken. The system elements that would address this requirement are the same as described in the takeoff flight phase.

From the above, the following building block system elements are viable candidates for the CRT based system concept:

- GPS
- Display (HUD and/or HDD)
- Sensor imagery Note: Overlay of charts and sensor imagery requires scale correlation
- Data link display
- Mass data storage
  - Airport layout charts
  - Departure charts (with special airspace boundaries)
  - Terminal area terrain contours
- Data link/voice for real time communications
  - Departure ATC instructions /validation
  - Weather services
- TCAS
- Sensor(s)
  Windshear detection
  Severe weather detection
  Target/intruder detection (potential)
  Detection of hazardous obstacles
  Vortex detection

2.4 Cruise

The operational requirement for the cruise flight phase is to avoid hazards arising from other aircraft, terrain and meteorological conditions and to maintain accurate navigation according to flight plan under normal and non-normal situations.

The top-level functional requirements for the takeoff flight phase include:

- Maintain and control desired flight path
- Detect and avoid airborne hazards to ownship
- Maintain safe separation from all types of airborne traffic
- Maintain safe separation from ground obstacles (man made & natural)
- Determine location and severity of atmospheric conditions (i.e. windshear, severe weather)

As in the departure flight phase, the primary focus in this flight phase is maintaining the desired flight path and avoiding obstructions/traffic/hazards. Again, the SVS/EVS should provide the flight crew with information that enables them to independently verify the safety of ATC instructions in a timely fashion. Stored data supplemented by position information and real time sensor data could provide this information. One issue that will arise when evaluating new enhanced weather radar as the potential sensor for this function will be the ability of the radar to provide simultaneous weather and ground map information. Antenna pointing/scanning is the issue --simultaneously scan weather on the horizon and ground map below the airplane.

The availability of GPS as an additional sole source navigation system coupled with existing IRS/radio navigation capability should provide the flight crew with adequate information concerning navigational compliance with flight plan. The improved ground mapping capability could provide another enhancement for flight crew awareness to gross navigation blunders where ground returns are available. TCAS, CDTI and ADS-B can all provide the flight crew with information regarding other airplane traffic. The implementation of Automatic Dependent Surveillance using GPS will provide ATC with a database of highly accurate positions for all aircraft in the operating environment. Data link/voice communications via satellite will correct surveillance/ communication deficiencies where airplane is beyond the line-of-sight of ATC.

The flight crew needs a depiction of the location and severity of impending hazardous meteorological conditions (e.g., thunderstorms, hail, volcanic ash) and obstacles (e.g., terrain) so that timely avoidance action can be taken. This would include meteorological conditions along route of flight and between own aircraft and diversion airports. The improved weather radar will support this requirement in a limited manner: i.e., line-of-sight. However, it will be the improved weather reporting via data link that will be most beneficial. Thunderstorm location/ tracking will be further enhanced by the new meteorological reporting. Clear air turbulence is another environmental condition that deserves consideration. Similarity between the detection of vortices and CAT may provide some capability for CAT detection. Determination has to be made when, how and even if this information should be displayed on an SVS/EVS tactical flight display to assist the avoidance of the hazard. Terrain depiction is especially important for the cruise flight phase during non-normal conditions such as engine-out drift down.

From the above, the following building block system elements are viable candidates for the CRT based system concept:

- GPS
- Display (HUD and/or HDD)
  - Sensor data
  - Data link display
  - Special airspace boundaries
  - Situation of other aircraft in area
- Data link/voice for real time communications
  - Enroute ATC instructions /validation
  - Weather services
- TCAS
- Sensor(s)
  - Improved ground map for position/path validation
  - Severe weather detection
  - Target/intruder detection (potential)
  - Detection of hazardous obstacles
  - Potential CAT detection
- Mass data storage
  - Enroute terrain altitude data

2.5 Descent and Final Approach

The operational requirement for the descent and final approach phases of flight is to safely descend for approach in normal or abnormal airplane configuration, while avoiding terrain, obstacles, hazardous weather, and other traffic during visibility condition, including at least CAT IIIb, and to do so independent of airport type.

The top-level functional requirements for the takeoff flight phase include:

- Maintain and control desired flight path and energy state
- Detect and avoid airborne hazards to ownship
- Maintain safe separation from all types of airborne traffic
- Maintain adequate separation following other airborne traffic
- Maintain safe separation from ground objects along ownship's flight path and landing zone
- Determine location and severity of atmospheric conditions (i.e. windshear, wake vortices)
- Determine position with respect to desired airport runway
- Determine SVS/EVS status prior to and during approach
- Comply with published instrument procedure and missed approach procedure appropriate for the airplane

- Determine information needed to take over visually at any point along approach and complete approach and landing to a runway suitable for airplane
- Comply with obstruction clearance radius for circling approach
- Determine ownship position in apace relative to any and all points on published instrument approach procedure for the airplane
- Compensate for crosswind and angina out conditions
- Distinguish between runway, and overrun, displaced threshold

The information required to verify the safety of ATC instructions independently in a timely fashion is the same as the requirements for other flight segments. However, the greatest challenge for this requirement will be the fusion of the information available and how to present it to the flight crew for accurate/ reliable interpretation. The stored data will be unique for this flight segment (e.g., terminal contour data, manmade obstacles, etc.). It will be necessary to compare this information with the stored flight plan for the optimum verification of safety.

A key to the operational benefit of the SVS/EVS concept is to provide sufficient information to conduct manual or automatic approach in CAT IIIb conditions at airport types down to and including unimproved airports. This means that the airplane is autonomous in its operations (except for satellite communication/navigation -- including differential GPS). There may be supplementary support from outside the airplane systems, but as a ground rule, none will be assumed initially. The requirement imposes the need for accurate/real time positioning of the airplane as provided by differential GPS. This positioning must meet requirements for sole source navigation. The supporting architecture must also provide redundant guidance to the airplane to allow automatic and/or manual control through the final approach segment. Independent real time situation verification must be provided the flight crew. At least a portion of this awareness could be provided by a sensor(s) through the descent and final approach segments. This sensor data may augment stored data and/or other computed information. It will not be assumed that there are any external aids (navigation /communication/ surveillance) available during the initial architecture definition except for the above defined satellite communication/navigation. The above operation does not preclude using features that are available in the improved ATC environment.

The flight crew must be provided sufficient information to maintain precise energy management of aircraft and accurate flight path control to touchdown point. A multi-element solution may be needed to meet this requirement with data from a sensor providing range/range rate to touchdown coupled with flight path calculations within the autothrottle and/or FMC as an independent data source from database generated information. This may be forcing requirement for the system in CAT Illb conditions.

The system should enable the flight crew to confirm wind conditions for entire descent, approach and landing. Improved weather reporting and data link availability will significantly improve flight crew information in this area. If there is no ground radar for real-time monitoring, then there will be the possibility of changes from gust fronts if traffic is not dense enough to track these dynamic changes.

So that timely avoidance action can be taken, information requirements are the same as for other flight phases for the awareness of: the relative position of nearby airborne aircraft, and aircraft and vehicles on active runways or aircraft holding for takeoff; the location and severity of impending hazardous meteorological conditions (e.g., windshear, wake vortices); and location and severity of impending hazardous obstacles (e.g., terrain).

From the above, the following building block system elements are viable candidates for the CRT based system concept:

- Differential GPS
- Display (HUD and/or HDD)
  - Airport layout charts
  - Sensor data
  - Data link display
  - Approach charts
  - Situation of other aircraft/vehicles/hazards in area of the runway
  - Airport area elevation contour data
- Data link/voice for real time communications
  - Descent and final approach ATC instructions /validation
  - Weather services
- TCAS
- Sensor(s)
  - Ground map/position data
  - Predictive windshear detection
  - Detection of other aircraft/vehicles near runway cleared for use
  - Vortex detection
- Mass data storage
  - Airport area elevation contour data

2.6 Landing and Rollout

The operational requirement for the landing and rollout flight phases is to make a safe, stable touchdown within the normal zone in any normal or abnormal airplane configuration, and to accomplish rollout and deceleration to safe taxi speed.

The top-level functional requirements for the takeoff flight phase include:

- Determine position with respect to correct runway
- Maintain safe separation with all types of airborne traffic
- Track and maintain runway center line
- Determine runway is cleared of traffic
- Maintain safe separation from ground obstacles (man made & natural)
- Determine runway boundaries, threshold and overrun
- Determine touchdown point and runway marking information
- Determine and comply with information currently provided by taxiway markings and facilities
- Maintain safe rate of descent and speed
- Determine flare location and magnitude
- Track and maintain runway boundaries for go around
- Determine the rate of nose wheel touch down
- Compensate for crosswind and engine out conditions
- Maintain airplane control during high speed roll
- Track and maintain runway center line during rollout
- Determine rate of deceleration for safe stop or taxi exist
- Determine safe runway speed for runway condition
- Determine appropriate taxi exit
- Identify and maintain safe distance from runway boundaries
- Determine and comply with information currently provided by runway markings
- Detect and avoid moving and fixed ground objects around ownship's path on the runway
- Determine position and direction of movement with respect to runway layout
- Determine the lighting/information provided by runway facility
- Detect and avoid airborne hazards to ownship
- Maintain adequate separation following other traffic

The objective of this flight phase is to provide the flight crew with sufficient information to conduct manual or automatic landing and rollout in CAT Illb visibility conditions as a minimum, which implies a need for rollout guidance. Acceptable rollout guidance could be provided by precise position information combined with an accurate representation of the runway environment, or by a sensor-generated representation of the runway environment or by a beam generated runway centerline. As with the descent and final approach phase, the appropriate redundancy levels must be provided to meet certification requirements.

High-speed exits and runway turnoffs can be identified by a combination of airport charts/layout, position sensors and system components already described to support other operational segments on the airport surface. For high-speed turnoffs, the data required may include range and range rate from airplane position to exit with acceptable speed bounds displayed versus actual speed.

For some landing and rollout operations, confirmation of landing and stopping performance to assure compatibility with performance calculation (i.e., confirm actual vs planned performance) may be needed. Based upon differential GPS, airplane position on the runway, remaining length of runway and current deceleration rate, it may be possible to predict if the airplane will stop on the runway. This will be a real-time/continuous calculation from the time the flight crew initiates any deceleration action to when the airplane achieves some predetermined speed.

From the above, the following building block system elements are viable candidates for the CRT based system concept:

- Differential GPS
- Display (HUD and/or HDD)
  - Airport layout charts
  - Sensor data
  - Data link display
  - Situation of other aircraft/vehicles/hazards in area of the runway
- Data link/voice for real time communications
  - Landing and rollout ATC instructions /validation
- Sensor(s)
  - Centerline detection/ tracking
  - High-speed exit detection
  - Runway turnoff detection
  - Detection of other aircraft holding or moving near runway
- Mass data storage
  - Airport surface charts

3.0 System Capabilities

The stated goal of the SVS/EVS Program (Norman, (3)) is to eliminate visibility-induced errors for all aircraft through the cost-effective use of synthetic/enhanced vision displays, worldwide terrain/obstruction/airport databases, integrity monitoring and forward-looking sensors as required along with Global Positioning System navigation. Although the primary goal is to eliminate the visibility-induced accident precursors, operational benefits must also be considered in order for the system to be cost-effective.

Ultimately, the system could allow a flight crew to safely takeoff, land, and taxi in visibility conditions down to and including CATIIIb, at any airport capable of operations during clear weather. Approach and landing will be accomplished without the necessity for ILS/MLS equipped runways. In addition, the system will provide the ability to avoid hazards such as terrain, other aircraft, and weather. Since SVS/EVS will probably be implemented in stages, the industry has defined a number of capabilities that will allow the system to grow past its initial release design. The initial design could include one or more of these capabilities.

In February 2000 NASA held a workshop in which they asked a cross section of representatives from industry and research organizations to address the Concept of Operations for the Synthetic/Enhanced Vision System. The goal of the workshop was to identify system capabilities that would provide safety benefits as well as operational benefits in gate-to-gate flight operations. The results of this workshop combined with a survey performed under the current contract indicate that although there are some potential safety benefits in the up-and-away flight segments (departure, cruise, descent), it is the takeoff, approach, landing, and taxi flight phases that will provide both the safety and operational benefits needed to make the system cost effective.

One of the key elements identified for determining the perceived operational benefits of a specific capability is the ability to get the benefit as the kickoff customer, without depending on the equipage of the rest of the airplanes in a given airspace. For example, Alaska Airlines got operational benefits from installing a Head-Up Guidance System in their B727 airplanes even though there were no other airplanes equipped with HGS flying in the same route system in which Alaska flew. They got the benefits as the HUD kickoff customer, right out of the box, without having to wait for infrastructure changes or other airlines to implement the system. This is an extremely important concept because mixed fleet operation is going to be the norm. If a capability is dependent on all airplanes in a specific airspace being equipped in order to generate the operational benefit (e.g., VFR operations in IMC or simultaneous parallel operations in IMC), then the benefit will be limited to those only cases when the equipage requirement is met thus reducing the value of the benefit.

The following are descriptions of operational capabilities that were proposed as providing both operational and safety benefits. Three of the capabilities involve approach, landing, and take off functions. One will allow the use of a CAT I ILS to land in CAT IIIa visibility. Another will allow aircrews to approach and land on runways with no ILS/MLS systems in weather down to CAT IIIa (700 ft. runway visual range). The third identified capability will allow the use of a CAT II ILS to land in CAT IIIb (as low as 300 ft. RVR) visibility. All three capabilities include the ability to take off in the visibility conditions specified.

The first capability illustrated in figure 3-1, will allow aircrews to approach, land and take off on runways equipped with a CAT I ILS/MLS in weather down to CAT IIIa. Using this capability the flight crew will perform a precision approach using the ILS to get down to the CAT I decision height. At or before the decision height is reached, SVS/EVS will be required to provide a visual display of the landing runway capable of allowing continuation of the approach down to 50 ft. Functions performed by the system involve the presentation of the runway environment from 300 ft. down to 50 ft (the CAT IIIa decision height) where the visibility must be sufficient to see the runway environment. The runway environment includes runway centerline, edges, and touchdown zone. This will require a display of the desired vertical path angle and an extended runway centerline to allow the pilot to align with the runway and maintain vertical situation awareness. An approach made using this capability will be required to be at least as accurate as an approach and landing made during VMC. Go-around capability will be required from any point on the approach to touchdown. This capability also includes the ability to detect and display ground obstacles from the air and while on the ground. Take off functions associated with this capability provide the ability to perceive the runway and objects on it from 700 ft out to the required braking distance for a worst-case rejected takeoff. This capability will open runways equipped with a CAT I ILS when they would ordinarily be closed and would reduce the number of flight and ground delays and diversions.

The second identified capability will allow flight crews to approach, land, and takeoff on runways with no ILLS/MLS systems in weather down to CAT IIIa. This effectively turns visual runways into precision runways. The approach functions involve the presentation of a visual image of the airport and runway environment from the RNAV hand-off point (1100 ft. Height Above Touchdown) down to the CAT IIIa 50 ft DH where the visibility must be sufficient to see the runway environment. The runway environment includes runway centerline, edges, and touchdown zone. An approach and landing made using this capability will be required to be at least as accurate as an approach and landing made during VMC. This will require a display of the desired vertical path angle and an extended runway centerline. Go-around capability will be required. . This capability also includes the ability to detect and display ground obstacles from the air and while on the ground. Functions for take off provide the ability to perceive the runway and objects on it from 700 ft out to the required braking distance for a worst-case rejected takeoff. Figure 3-2 illustrates the takeoff and landing parameters required for implementation of this capability. The benefits to an airline include being able to get into and out of small airports while reducing the risk of becoming grounded due to low visibility conditions. Runways never before used for precision approaches will be open in low visibility conditions. This will impact airlines servicing countries where the number of ILLS equipped runways is much lower than the USA.

The third approach and landing capability will allow flight crews to approach, land, and take off on runways equipped with a CAT II ILS/MLS in weather down to CAT IIIb as shown in Figure 3-3. Requirements for this capability involve the presentation of the runway environment from 200 ft. down to the commencement of flare. An approach/landing made using this capability will be required to be at least as accurate as an approach/landing made using a CAT III ILS and an autoland system; the ability to perform a go-around is included. Because there is no decision height, this will be a fail operational system. Takeoff functions provide the ability to perceive the runway and objects on it from 300 ft out to the required braking distance for a worst-case rejected takeoff. This capability will open runways equipped with a CAT II ILS when they would ordinarily be closed and would reduce the number of flight and ground delays and diversions.

A surface operations capability could permit the flight crews to taxi in visibility conditions down to 300 ft. RVR. Functions producing this capability include the display of the information provided by runway and taxiway markings, signs, lights, and color-coding schemes and display of the cleared taxi route. The position data must be precise enough to enable the flight crew to verify that the aircraft is on the assigned taxiway. In addition, a function will be necessary to detect and avoid obstacles and to detect other aircraft/vehicles in the immediate area and to display them with enough precision so that the flight crew can avoid them or follow them. The benefits of this capability are tied to the take off and landing capabilities since taxiing will be required in the same visibility conditions. This capability is also of benefit in VMC especially complex or unfamiliar airports and at night. As pointed out in the ConOps Workshop and by the industry survey, surface operations occur twice every flight leg. Therefore, operational benefits that can be attributed to this flight phase may be weighed more heavily than those that are accrued during low visibility air operations, which occur much less frequently.

A terrain awareness capability involves the display of terrain data all operations that take the airplane close to terrain as well as for route planning. Required functions involve the inclusion of strategic planning displays for the avoidance of ground obstacles and an immediate tactical flight path display using database information or sensed data. Strategic planning involves checking the flight path entered into the Flight Management Computer for terrain conflicts as well as database information along the current flight path it will also enable planning emergency and off route descent terrain clearance. The immediate tactical flight path display will be used to ensure that the actual near term flight path is clear of obstacles. It will also be used to verify terrain alerts and to facilitate the execution of escape maneuvers.

A traffic separation capability will provide information to detect and resolve traffic conflicts. It could also permit flight crews to operate in the terminal area using visual flight rules in weather associated with Instrument Meteorological Conditions. This includes lateral and longitudinal separation from other aircraft as illustrated in figure 3-4.

Functions necessary to achieve this capability involve sensing and displaying the area around the aircraft to a distance of at least thirteen miles (the distance needed to give a 45 second alert with two airplanes, in cruise, closing head on at a closing speed of 1200 knots.). This sensing distance will permit operations that could allow airport traffic flow to remain at levels close to normal even during low visibility conditions. This will reduce the number of passengers impacted by delays and cancellations and therefore increase the revenue to our customers.

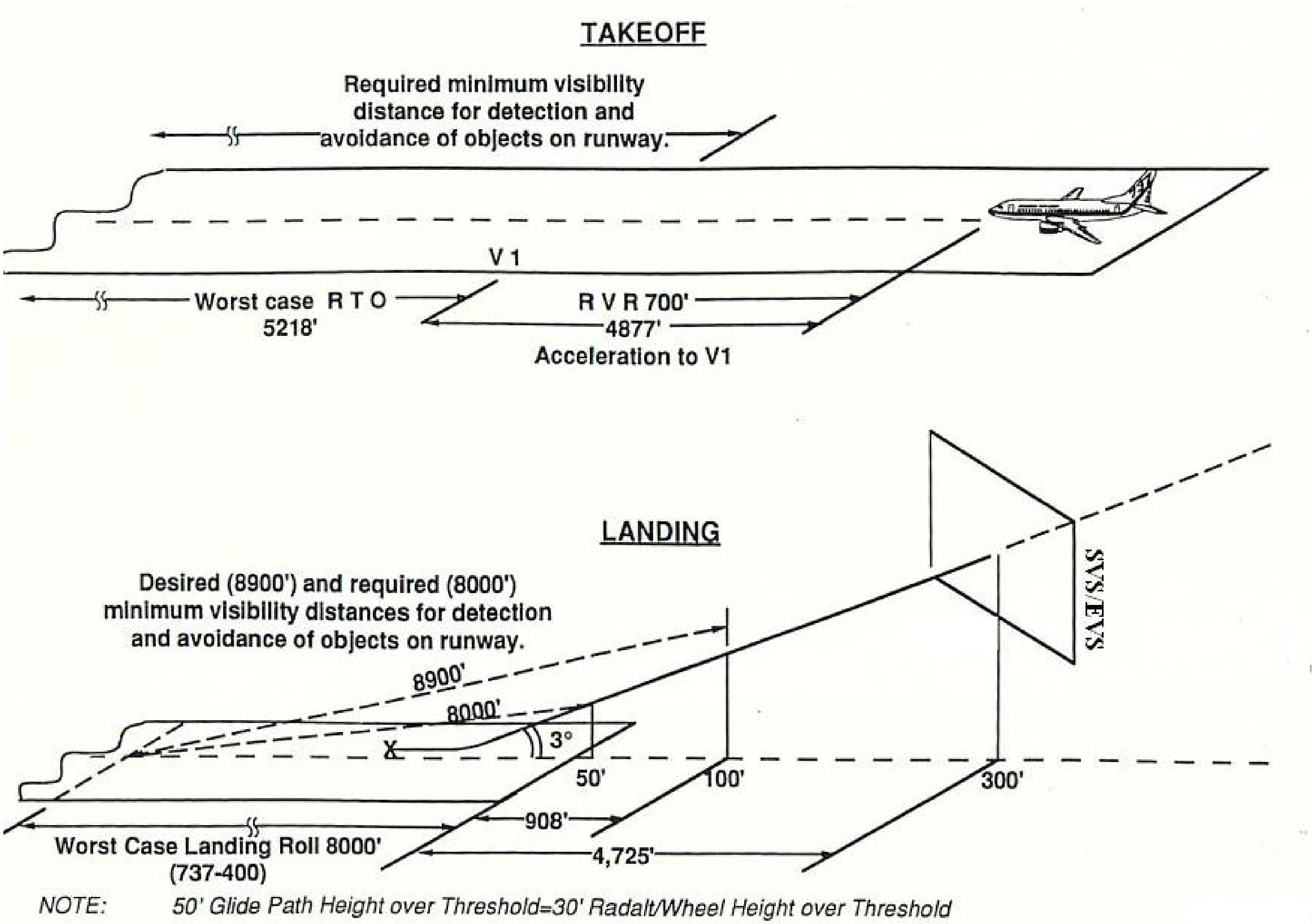

Figure 3-1.Capability to take off and land at a CAT I facility in visibility conditions down to CAT IIIa (Example using a B737-400)

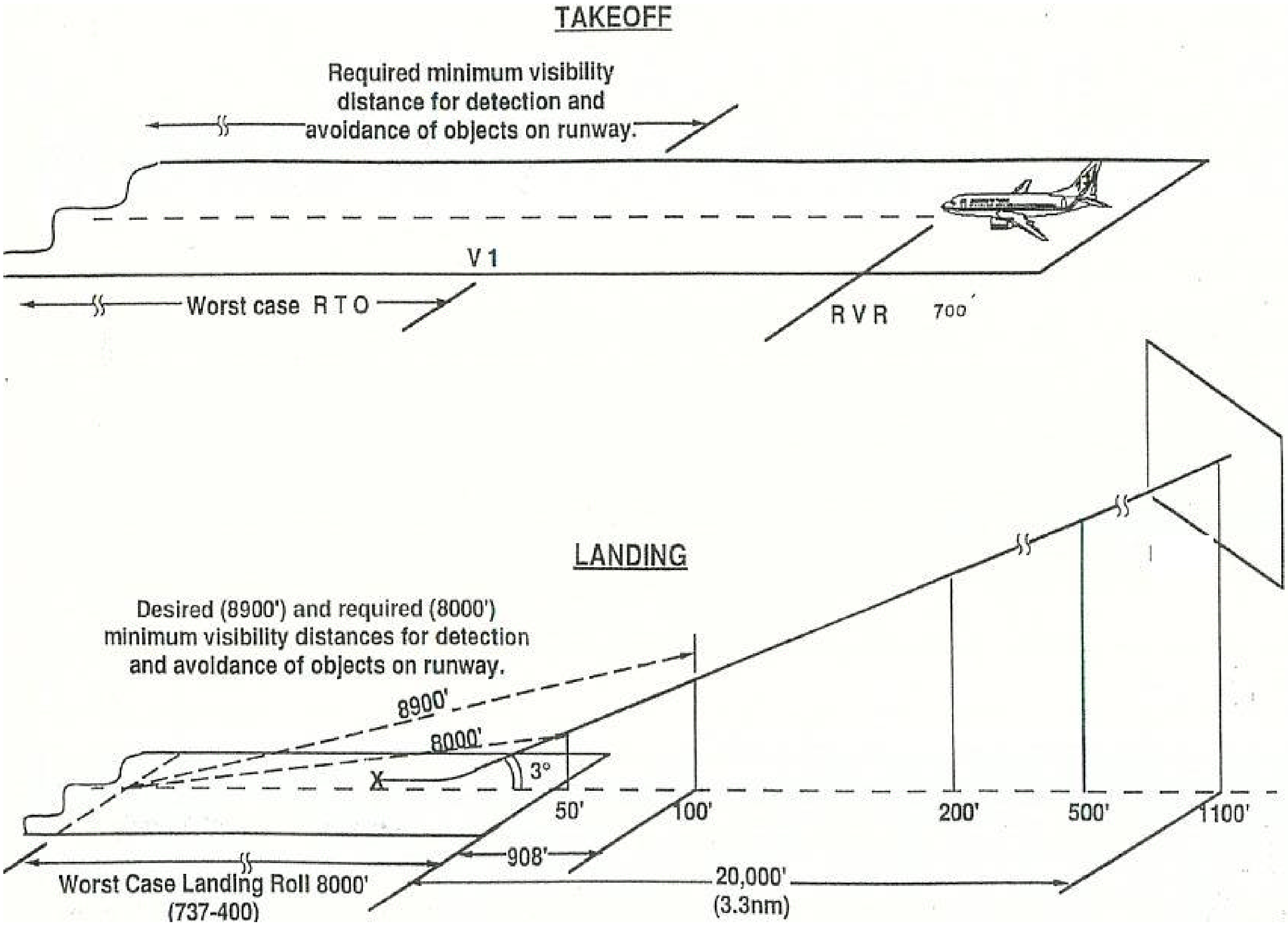

Figure 3-2. Capability to take off and land on a non-ILS facility in visibility conditions down to CAT IIIa (Example using a B737-400)

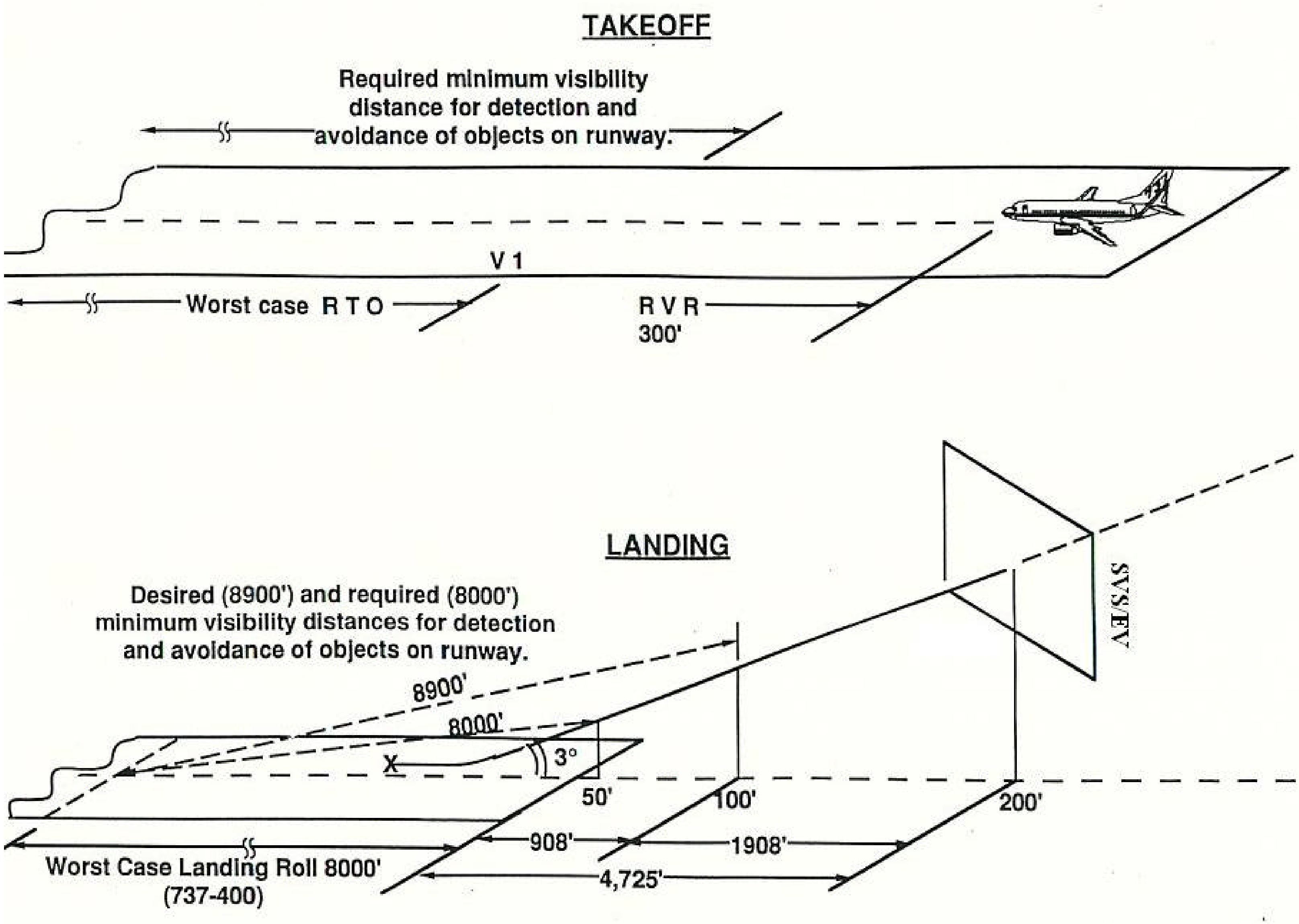

Figure 3-3. Capability to take off and land at a CAT II facility in visibility conditions down to CAT IIIb (Example using a B737-400)

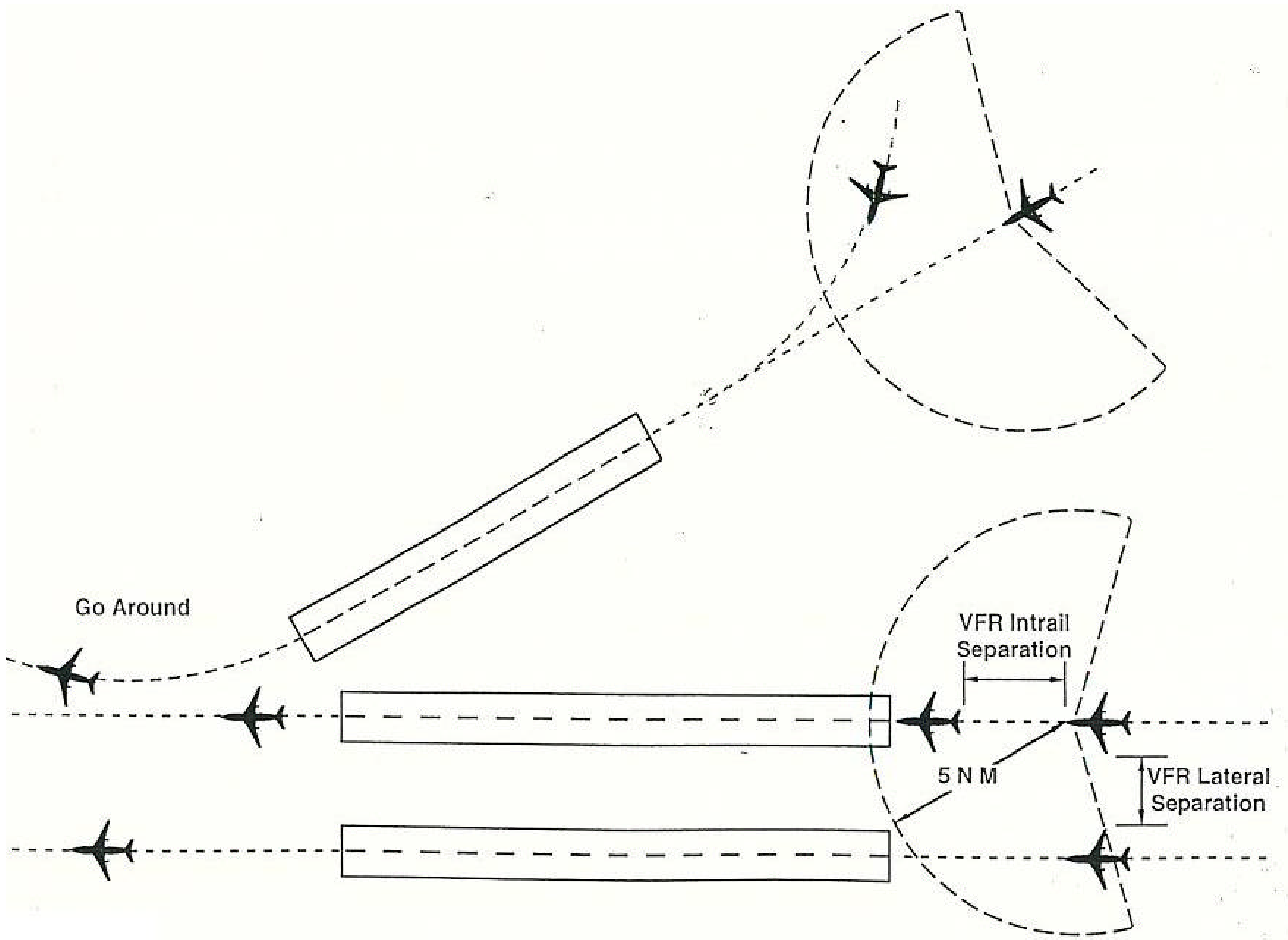

Figure 3-4. Capability to operate in the terminal area using Visual Flight Rules in visibility associated with Instrument Meteorological Conditions.

4.0 Candidate Concepts for Airplanes with CRT Type Displays

The results of an industry audit support the data presented by Koczo, et.al. (1998)[4] that only approximately 34 percent of the commercial transport airplane fleet currently in service have CRT/LCD type of display technology (with a very small number being LCD equipped). The retrofit issues for the CRT equipped airplanes make this approach for SVS/EVS implementation extremely problematic. There is no excess graphic capability in any of the currently flying graphic generators. Given that the displays must meet certification brightness levels, there is no write speed left in any of the current CRT displays to incorporate more symbology. Thus, without a significant upgrade to the existing equipment. The SVS/EVS tactical functions are not achievable on the head-down displays. The industry is moving towards an LCD upgrade to both and-on and retrofit airplanes. This upgrade would provide the opportunity to incorporate the SVS/EVS functionality in the head-down displays. The positive side of this strategy is that the SVS/EVS will not have to absorb the cost of the upgrade in its cost/benefit justification. The down side is that the implementation will be prolonged to such an extent that it will have little impact on the safety goal.

4.1 Phased Implementation Approach

One way to accelerate implementation and take advantage of the benefits from the system is to initiate a phased implementation strategy in which the capabilities that are the “low-hanging fruit” are the focus of the initial efforts and the higher risk functionality phased in at a later date. In this strategy, the systems engineering approach mentioned earlier is used to evaluate the desired capabilities of the system using requirements, cost/benefits analysis, technology readiness and resource availability as the trade criteria. To evaluate the technology readiness of a candidate concept it is necessary to determine just what the operational concept is and then to define what equipment will be needed to implement the concept. The trades will consider how much existing equipment (low risk) can be incorporated into the concept and how much new equipment is needed. Also considered will be how much technology outside of the airplane will be required (i.e., ground or satellite equipment). Further what changes in the infrastructure (airport or airlines) and in procedures are needed to support implementation. Finally, it is necessary to determine the risks associated with the candidate concept (e.g., technical, time, infrastructure, certification, etc.).

Lastly for each of the candidate concepts and the resulting capability, it is necessary to ask if the resources exist to pursue the concept. It should be determined if the research resources are available to resolve the remaining issues associated with the concept. Given the costs associated with implementation, determine if the potential customers have the resources available (and the willingness to expend them) to implement the concept. For the risk profile of the technology, it must be determined if the suppliers have the resources available to produce the concept.

The results of the above analysis will determine in what order the capabilities should be phased in to implementation and how the system should evolve. Using a building-blocks approach (see Figure 4-1), candidate concepts can be defined that achieve the desired capabilities and are positioned to efficiently and cost effectively evolve into concepts that provide the higher order capabilities. Figure 4-2 graphically presents a notional depiction of a system evolution with the evolving capabilities and the additional system components needed to support the evolution.

4.2 Baseline Concept

The baseline concept is composed of technology that is either currently in service or close to being certified for line service. The assumptions for the baseline system are that the airplane is equipped with a CRT type Electronic Flight Information System (EFIS), a CRT based Vertical Situation Display, a Head-up Display, FMS, standard avionics and navigational equipment, TCAS/CDTI, EGPWS and it's database, airport database, weather radar and predictive windshear. Norman (3) in describing a concept of the Synthetic/Enhanced Vision System, provides an excellent functional description of all of these system components. The HUD use philosophy would be consistent with that stated by Norman (3) in that the HUD would be employed as a Primary SVS/EVS tactical display, but the philosophy would still be to consider the existing head-down EADI/PFD as the Primary Flight Display.

The capabilities provided by the baseline concept include: flight operations into Type I certified facilities during all visibility conditions down to and including CAT IIIa conditions; terrain separation during all phases of flight; and traffic conflict detection and resolution. As stated above, an audit of the industry has indicated that current transport category airplane symbol generators and CRT displays cannot accommodate the additional information that would be needed for the implementation of the current SVS/EVS concept. Therefore, a head-up display surface would be used to provide these capabilities. Alaska and Southwest airlines have shown that a Head-up Guidance System (HGS), using a flight path vector, a “wire-frame” representation of the runway environment and a flare cue, is an economically viable way to upgrade a two-channel autopilot system into a three channel system which provides CAT IIIa autoland capability. Although the original HGS STC required that the airport be certified to the same visibility conditions as the airplane and crew (i.e., in order for an airplane to land in CAT IIIa conditions, the airport has to be a Type III facility), subsequent certification efforts have permitted, on a case by case basis, lowering the minimums below the facility certification. In order to operate on Type I facilities in CAT II and CAT III visibility conditions, it may be necessary to provide the appropriate runway lighting and markings on the head-up representation. Therefore, the baseline concept will have a Head-up display with “wire-frame” representation of the runway environment.

Terrain information is currently being provided by a Terrain Awareness and Warning System (TAWS) which uses the map display and alerting system to ensure terrain separation (see Figure 4-3). The weakness of this system is it’s inability to display conflicts during the final approach phase and glideslope capture. The addition of a Vertical Situation Display (VSD) mitigates this weakness and provides the flight crew with better awareness of the airplane’s vertical position relative to the planned flight path (see Figure 4-4). Such displays are currently being proposed as options on airplanes with with better awareness of the airplane’s vertical position relative to the planned flight path (see Figure 4-4). Such displays are currently being proposed as options on airplanes with CRT type EFIS and will be flying in line service in the very near future. TAWS and the VSD combined with the map/NAV display will provide the flight crew with spatial awareness that will permit both strategic planning and tactical airplane operations in both the horizontal and vertical planes.

TCAS is the system component currently used in combination with ATC to provide traffic separation. Cockpit Display of Traffic Information (CDTI) implementations are working their way through the certification process. Unlike TCAS which uses the Mode-S transponder to detect and resolve traffic conflicts, CDTI makes use of a number of detection elements beside the Mode-S transponder (e.g., ADS-B and TIS-B). This multi-functional approach can produce more accurate data and open the system up to more functionality. For example (from SAE ARP 5365[5]) CDTI would enhance the In-Trail Climb (ITC) and In-Trail Descent (ITD) procedures that have been certified on a trial basis for certain portions of US air traffic service provided oceanic airspace. The current procedures authorize the use of the TCAS II traffic display for climbs or descents through the altitude of same direction traffic at separations considerably lower than standard non-radar separations, when certain display adequacy requirements are satisfied and the required training has been accomplished.

The procedures require positive identification of the lead aircraft and an establishment of closure rate by the trailing aircraft. These requirements are currently accomplished in a somewhat cumbersome manner through voice communications and the use of transponder squawk-standby procedures. The CDTI could significantly enhance these procedures by providing the identity of the traffic and the closure rate on the traffic display. A minimum reception and display range of 20 nmi would be required, but longer reception ranges of up to 120 nmi would provide increasing benefit by proportionately increasing the applicability of the procedure. The range readout is currently required to be accurate to within a mile, and therefore the CDTI must also meet that requirement. The procedure is sensitive to the value of the closure rate, allowing a maximum of 20 knots closure between the two aircraft to initiate the climb.

It could also be used to facilitate station keeping in oceanic, en route, and remote non-radar airspace. Station keeping is the monitoring of longitudinal and/or lateral distance once a desired interval has been established. During station keeping in non-radar airspace, ATC could instruct the flight crew to maintain a specific distance from a lead aircraft (say 20 nmi). The flight crew would then use information derived from the CDTI to judge maneuvering of own aircraft to maintain the specified distance. Initial implementations of this concept may be procedurally based, similar to the ITC/ITD, and not require any change in separation responsibility.

A final application of CDTI is to take the first step in providing limited closely spaced parallel runway operations in IMC. The Closely Spaced Parallel Approaches (IMC) application is an alternative for providing the safety required to conduct parallel ILS approaches to the current minimum spacing for wake turbulence independence, 2500 ft, or potentially even closer runway spacing. After standard separations are lost during the respective “turn on” to the final approach courses, separation could be provided procedurally through navigation on the localizers. The CDTI could be used to assist flight crews in maintaining tight stagger position control throughout such approaches. Conflict resolution logic would be used as a backup to prevent a collision hazard in the event of an error or navigation blunder.

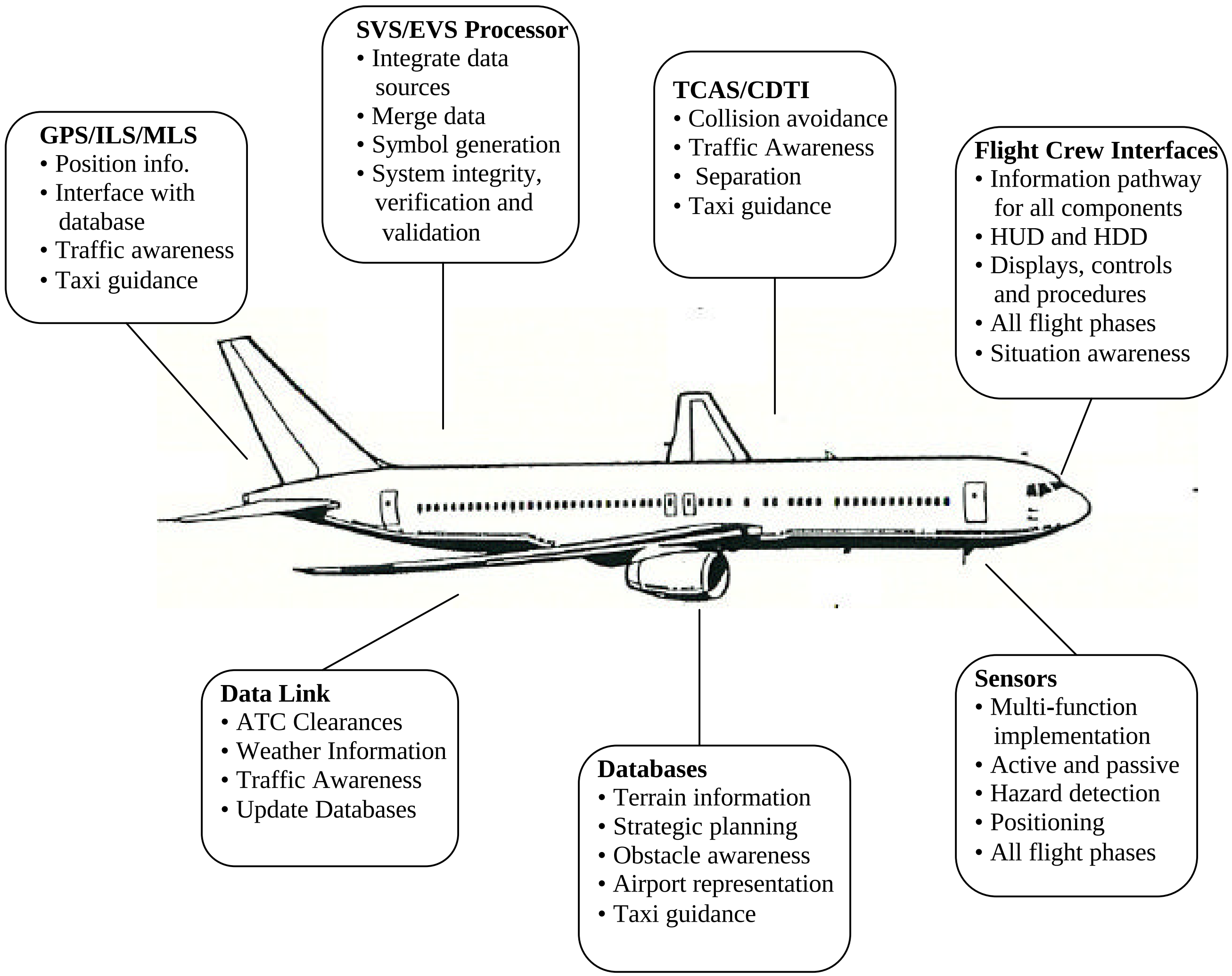

Figure 4-1. Example of system building blocks approach

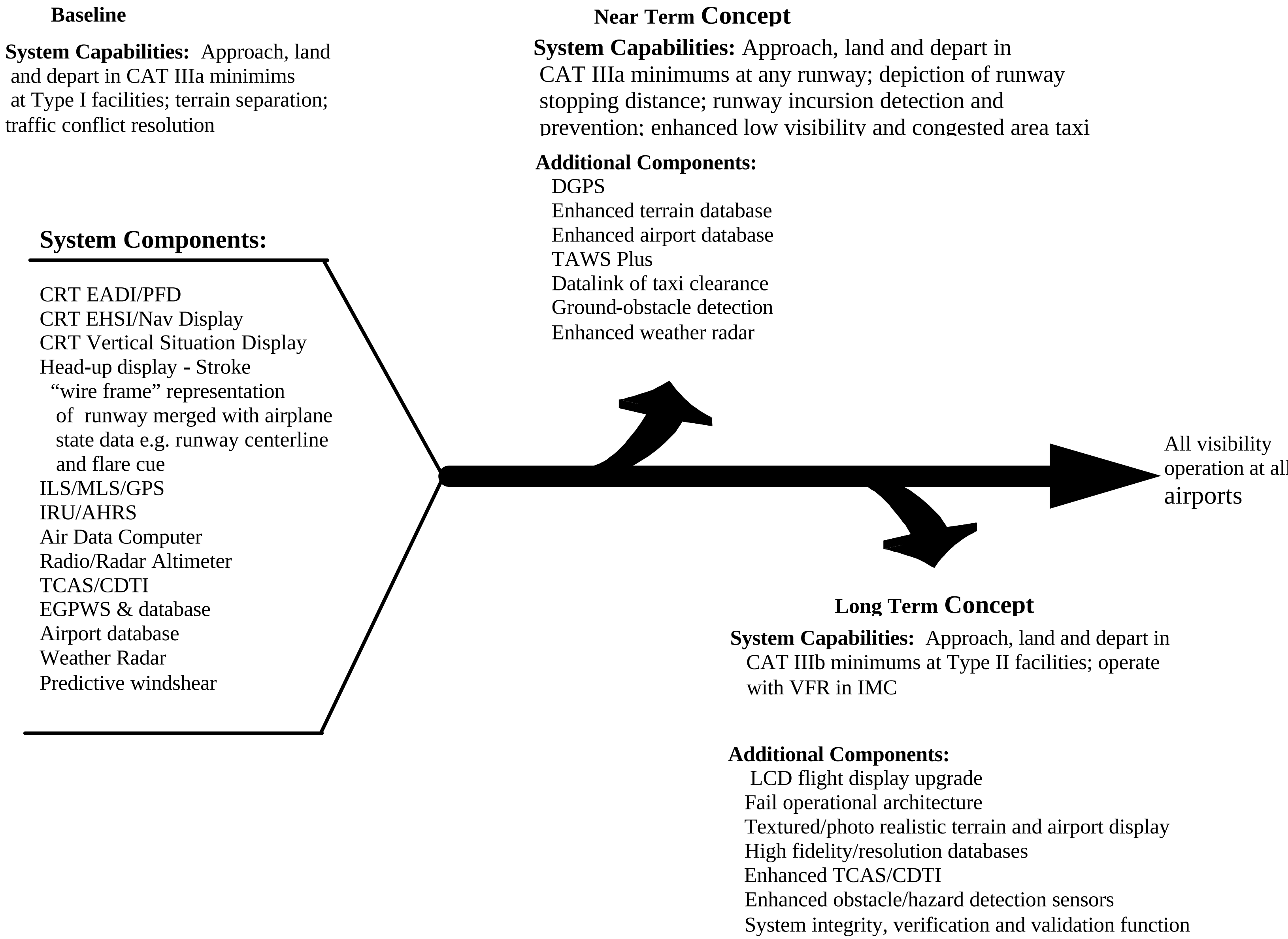

Figure 4-2. Example of a candidate system evolution

Figure 4-3. Current TAWS presentation on a Map/NAV display

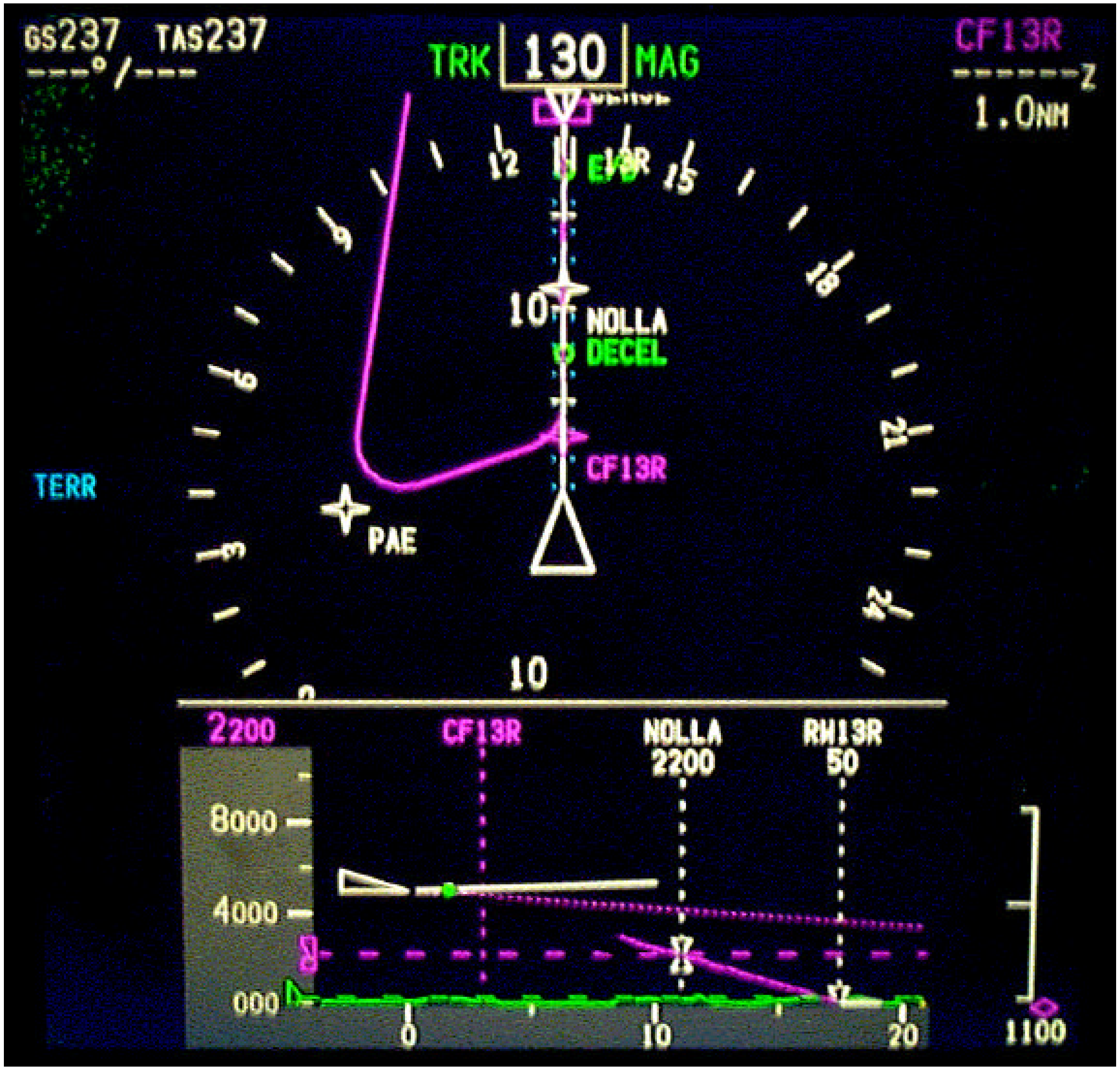

Figure 4-4. Combined Map/NAV display and vertical situation display both containing strategic and tactical information elements

4.3 Near Term Concept

The near term concept for CRT EFIS type airplanes uses technology that although it is less mature than that found in the Basic Concept, it has a high probability of being economically viable in the relatively near future. The implementation of the near term concept is not dependent on the upgrade of the flight displays to LCD technology. System components that would be incorporated in addition to those in the Basic Concept include: Differential Global Position System (DGPS); TAWS Plus; enhanced terrain database to provide higher fidelity and more expansive coverage of the terrain; enhanced airport database providing the airport surface information as well as the runway information; system integrity monitoring; datalink of the taxi clearance; enhanced weather radar to detect runway incursions; and a ground-obstacle detection capability. Again, Norman (3) provides an excellent functional description of these system components. As with the Basic Concept, the HUD would be the Primary SVS/EVS tactical display, the existing head-down EADI/PFD would be the Primary Flight Display, and the head-down EHSI/NAV display would be the in-air strategic planning and navigation display and on the ground the airport moving map display.

Capabilities provided by the near term concept include: flight operations into any runway in visibility conditions down to and including CAT IIIa visibility; depiction of runway stopping performance; detection and prevention of runway incursions; and enhanced low visibility and congested area taxi. The head-up display would still be a “wire-frame” presentation but would include more terrain features and more airport features to facilitate the transition to the Taxi mode. To gain these lower minima at non-precision facilities, it will be necessary for a precision navigation system (DGPS) to provide the primary approach guidance. This guidance signal will have to have the integrity and accuracy to allow the airplane and crew to fly to a conventional decision height. In order to perform CAT II and CAT IIIa operations on any runway it will be necessary to provide the appropriate runway visual references (e.g., lighting and markings, touchdown zone, etc.) on the HUD. As Koczo et.al. (4) point out, “the FAA requirements essentially require the pilot to judge whether the aircraft is in a position from which a descent and landing on the intended runway can be made using “normal" maneuvers”. On the approach the availability of a clear runway will have to be verified. Runway incursions must be detected and displayed. Upon the commencement of deceleration on the runway, the HUD could also provide an indication of the stopping distance given the current rate of deceleration.

The TAWS Plus component would provide better terrain awareness especially for airports that do not have precision guidance. Koczo et.al. (4) describe the potential improvements of the TAWS Plus implementation as:

1) Upgrade of the terrain display

The current TAWS / EGPWS uses a 2-dimensional (2-D) display that is low resolution, using the existing weather radar display. An upgraded “2-D Plus” display may be considered that provides higher resolution graphics with additional symbology. The display may also be upgraded to a 3-D terrain graphics display, with perspective or non-perspective views. Again, with these improved displays arises the issue of trusting the display more than is warranted by the underlying system integrity.

2) Using an improved terrain / obstacle database

The database can be improved to provide greater grid resolution and data accuracy. The current TSO for TAWS requires only a 0.25 nmi terrain grid spacing within 15 nmi of airports, 0.5 nmi grid spacing within 50 nmi of airports, and 300 nmi grid spacing for enroute operations. Databases with considerably greater grid resolution are becoming available and should offer improvements.

Note: An improved database does not necessarily assure improved database integrity. While the resolution and accuracy may be improved, the probability of undetected misleading information may be relatively high depending on the available database integrity. SVS databases and associated system issues are further discussed in Section 3.

3) Better alerting algorithms

With improved databases, improved aircraft navigation capabilities based on Required Navigation Performance (RNP), and improved aircraft trajectory prediction using aircraft intent information, further improvements in terrain avoidance alerting algorithms may be possible. TAWS / EGPWS is expected to provide a significant improvement in alerting performance (high success rate in detecting terrain conflicts, low false / nuisance alarms) versus GPWS. As operational experience is gained with TAWS / EGPWS, these algorithms can be further improved for TAWS Plus.

4) Improved evasive maneuvers / guidance

Addition of evasive maneuvers or using improved evasive maneuvers and guidance can be utilized to further improve TAWS Plus terrain avoidance performance. When used only as a safety system, TAWS Plus can remain a non-critical, ~10^{-5} integrity system. However, if TAWS Plus using evasive maneuvers / guidance is used to allow closer flight to terrain from a strategic and tactical perspective, the criticality of the system increases rapidly.

5) Supplemental Data

Supplementing the TAWS Plus terrain database with data derived from terrain mapping sensors / radars during flight operations. The benefits of using inputs from these enhanced vision sensors need to be investigated.

In the taxi mode, the HUD would provide the tactical taxi information and the head-down "Surface Operations Display" would provide an airport surface map depicting ownship location, traffic, obstacles, airport markings/lights, and the cleared taxi route. An accurate airport database is required along with DGPS navigation. Ground obstacle detection (dynamic obstacles and static obstacles) is needed to perform the taxi function.

4.4 Long Term Concept

The long-term concept for CRT EFIS type airplanes uses technology that will require major upgrades to the airplane in order to implement the concept and/or is high risk either developmentally or from a certification perspective. The component assumptions for this concept include: LCD EFIS upgrade; SVS/EVS capable symbol generators; fail operational system architecture; textured/photo realistic terrain and airport display formats; high fidelity/resolution databases; enhanced TCAS/CDTI; enhanced obstacle/hazard detection sensors; capability to fuse data from multiple detection sensors; components that will perform the SVS/EVS computational functions; system integrity, verification and validation function.

Capabilities provided by the long term system concept would include: flight operations into Type II certified facilities in visibility conditions down to and including CAT IIIb; and operate using visual flight rules in IMC Flight operations in CAT IIIb visibility are performed without a decision height which means that the flight crew does not have to visually acquire the runway environment in order to perform the landing. This operation requires a fail operational system with an architecture that achieves a flight critical integrity level. For a Type II facility, the Synthetic/Enhanced Vision System would augment the outside vision by providing a Type IIIb representation of the airport environment (including lights, markings and signs). Pathway-in-the-sky information and an out-the-window image could permit the flight crew to fly complex curved flight paths and, given that other aircraft are similarly equipped, fly simultaneous closely spaced parallel approaches in IMC. Visual Flight Rule spacing could be used on all approaches.

Using the SVS/EVS computational subsystem Norman (3) suggests that the following functions could be performed:

- Cleared and actual path depiction
- Hazard display integration and depiction
- Runway Incursion Prevention System algorithm computation and display
- Hold Short and Landing Technology algorithm computation and display
- Navigation and hazard situation awareness enhanced display element generation
- Alert and warning generation and presentation
- Overall display symbol generation and/or SVS/EVS integration
- Integrity self monitoring and alerting

Finally, an extension of the long term concept refining the technology and gaining in-service experience with the system could result in achieving the goal capability which is VFR operations in all visibility conditions at all airports.

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